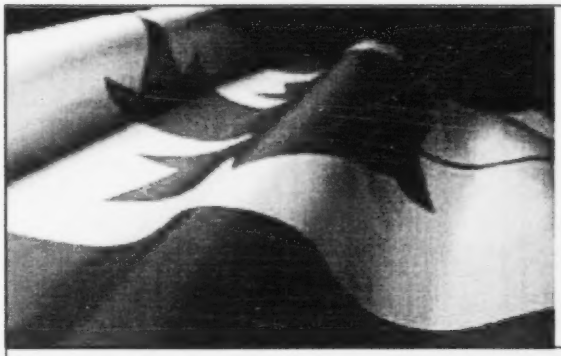

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Is Investment Not Sensitive to its User Cost? The Macro Evidence Revisited

by

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Abstract

A key parameter in determining the response of investment to changes in its price is the user cost elasticity. But the empirical evidence on the user cost elasticity is mixed.. Traditional macro-econometric estimation has yielded a value close to zero whereas newer micro-econometric estimates yield values closer to one. We re-examine the macro-econometric estimates to see whether there are any potential shortcomings in that approach. We identify three: whether a user cost shock is seen as permanent or temporary, potential endogeneity of the user cost, and aggregation errors. Introducing corrections for these problems yields elasticity estimates closer to those of the micro-based estimates.

Résumé

Un paramètre clé dans la détermination de la réponse de l'investissement aux changements dans son prix est l'élasticité par rapport au coût d'usage. Mais il n'existe pas de consensus dans la littérature empirique sur ce sujet. Les estimations macro-économétriques traditionnelles ont eu tendance à donner des valeurs près de zéro. En revanche, les estimations micro-économétriques plus récentes ont eu tendance à produire des valeurs plus proche de l'unité. Dans ce texte, nous examinons les résultats macro-économétriques afin d'identifier les sources de cette divergence entre les analyses macro-économiques et micro-économiques. Nous en identifions trois sources de divergence: il est important d'identifier si les changements de coût d'usage sont permanents ou temporaires; la présence probable d'endogénéité du coût d'usage; et l'utilisation de données d'investissement trop agrégées. En introduisant des corrections pour ces problèmes, nos estimations macro-économiques donnent des résultats plus proche de ceux obtenus à l'aide de données micro-économiques, c'est-à-dire, des valeurs de l'élasticité de l'investissement par rapport à son coût d'usage près de l'unité.

1. Introduction

Increased attention is being placed on fostering economic growth. Economic theory suggests that one of the prime factors responsible for increasing growth is physical investment, particularly in machinery and equipment.[1] However, ambiguity remains about the best policy to encourage investment.

In particular, macro-econometric analyses have suggested that the elasticity of investment with respect to user cost is close to zero.[2] This price elasticity of capital is one of the key parameters in giving an estimate of the benefits of tax reform.[3] Hence, changing the price of investment—by reducing taxes for example—would have little effect according to these estimates. But there are numerous econometric difficulties encountered with macro data, as outlined later in this paper.

Econometricians, reacting to these problems, began to examine panel data of individual firm behaviour.[4] They have challenged this conclusion of low elasticities by obtaining estimates with much higher elasticity estimates that range up to 1.0.[5] These newer studies use natural experiments such as the 1986 Tax Reform Act in the United States that led to dramatic changes in the tax treatment of investment, aspects that could be exploited by econometricians.[6]
The goal of the analysis presented in this paper is to revisit the macro-econometric analysis. We therefore retain the traditional neoclassical model. But, we try to understand the sources of differences between the micro and macro results. The first issue we tackle is whether shocks are permanent or transitory.

Firms base their investment decisions on expectations of the future so, because of the presence of adjustment costs, rational firms should only respond to permanent shocks. But one of the problems with macro data is that they are a mixture of both permanent and transitory effects, which are difficult to disentangle. So, data that consist mainly of transitory shocks should exhibit low responsiveness of investment to changes in the cost of capital. However, there have been sharp falls recently in the price of some components of machinery and equipment (M&E) investment, such as information and communication

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[1] See ab Iorwerth (2002).
[2] For a review see Chirinko (1993).
[3] In one of the original CGE analyses, the welfare gains from equalizing tax rates across industries increases by 70 per cent if the user cost elasticity is increased from 0.5 to 1.0. See Ballard, Shoven, and Whalley (1985) See also Chirinko (2002).
[4] Work in this area started with Cummins, Hassett and Hubbard (1994).
[5] For a review see Caballero, (1999) and Hassett and Hubbard (1997).
[6] The use of tax experiments could have two advantages: i) they represent exogenous price changes and ii) they are permanent. Both of these hopes have been criticized in the U.S. context however because i) there may be political desire to introduce tax changes when investment is low so that the price changes are not exogenous and ii) tax changes occur every other year in the U.S., which suggests that the expected tax rate could be viewed as random. The elasticity of capital with respect to user cost is also important in analyzing the transmission mechanism for monetary policy. (For a summary, see Bernanke and Gertler (1995)). Consequently, the use of tax changes led some to question if such an exercise is useful in analyzing the response of firms to other aspects of the cost of capital. But studies undertaken to examine the response of firms to changes in the cost of lending have also come to similar conclusions that the elasticity of investment with respect to user cost is around 1.0. (Guiso et al. (2002)).

technology (ICT) investment.[7] This secular and permanent decline in the price of ICT investment could have been seen as a permanent shock by firms and would have induced greater investment response. This decline may allow aggregate econometric analysis to obtain a more precise estimate of the responsiveness of investment to user cost.

In order to exploit this seemingly permanent price decrease, we restrict our sample to data from 1984 onward; the point at which the downturn in relative M&E user cost begins. We find evidence of cointegration (which confirms that there is an equilibrium relationship between the variables) but we obtain a statistically insignificant user-cost elasticity.[8] However, our elasticity on output is greater than 1, which contradicts the neoclassical theoretical prior that investment or capital are not on explosive paths. We therefore restrict the output elasticity to equal 1 and find a large negative user-cost elasticity of 0.97. We then undertake sensitivity analysis regarding our starting date but such changes do not alter our fundamental results.

A second issue we examine is the impact of using aggregated data. Aggregation may mean that different responses of investment subcomponents are washed out at the aggregate level. We use a decomposition of M&E into its component parts. Tevlin and Whelan (2003) found that such a decomposition was an important factor in explaining the performance of aggregate M&E in the U.S. during the late 90s. In our data, software and computers exhibit sharp falls in their relative user cost whereas other components (such as telecom equipment) do not. The data suggest that aggregate M&E is a mixture of these permanent and transitory effects, even though there is an overall fall in its relative price, which could explain low elasticity estimates.

Re-estimating the investment equations for each type of ICT investment leads to a correctly-signed and significant elasticity estimates of around 0.5 for computers and for software but again with excess sensitivity to output. The user-cost elasticity estimates are greater than 1.0 when we make adjustments for excess sensitivity of investment to output.

The divergence in user cost elasticity estimates between those with and without restrictions on the output elasticity highlights the third problem with macro data: the endogeneity of output and the interest rate (a component of the user cost).[9] Positive aggregate demand shocks may lead to increases in investment but also to higher interest rates as central banks raise interest rates. Such endogeneity leads to the output coefficient being biased upward and the price elasticity being biased downward.

We conclude that there are sound reasons for believing that traditional macro-econometric estimates of the user cost elasticity are not appropriate when one wants to assess permanent and sustainable changes in the cost of capital coming either from tax changes or other structural changes. Our findings suggest that taking advantage of permanent shocks, using more disaggregated data and accounting for endogeneity of

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[7] For discussion of recent changes see Tevlin and Whelan (2003).
[8] Our estimates are similar to those of Alain DeSerres (1995).
[9] Using an instrumental variables approach can rectify endogeneity problems. However, our efforts in this area were hampered by the absence of satisfactory instruments.

output result in macro-econometric estimates closer to those of the micro-econometricians.

The paper proceeds as follows. Section 2 discusses the modeling approach used in our analysis. Section 3 discusses the econometric difficulties in using macro data. Section 4 analyses the data and provides results from our regressions. Section 5 concludes and highlights avenues for future research.

2. Modelling and Econometric Approach

a) Theory

Following Hassett and Hubbard(1997), the firm maximizes cash flow given by

$$(1-\tau_t)(P_t F(K_{t-1}, N_t) - W_t N_t - G(I_t, K_{t-1})) - Q_t I_t (1-\Gamma_t) \quad (1.1)$$

Firm profits are given by $P_t.F(K_{t-1}, N_t) - W_t N_t - G(I_t, K_{t-1})$ where K is capital, I is investment, N is labour and $G(I,K)$ is the convex adjustment cost of undertaking new investment for a given a stock of capital. The presence of adjustment costs allows a well-defined investment function to exist but, in the following derivation, adjustment costs are assumed to be zero. Output is priced at p_t and new investment has a pre-tax price of Q_t. The tax system is modeled as a corporate income tax, τ, an investment tax credits, γ, and the present value depreciation allowances, z, so that $\Gamma = \gamma + z$.

The user cost of capital can be expressed as the marginal cash flow from an additional unit of capital. Hence differentiating (1.1) with respect to capital and defining this derivative as the user cost, C_t, leads to

$$C_t = (1-\tau_t) P_t . F_k (K_{t-1}, N_t) \quad (1.2)$$

Assume a CES production function for output $Y=F(K,L)$, is given by

$$Y = \left(bK^{-\phi} + (1-b)N^{-\phi}\right)^{-1/\phi}$$

where A grows at a constant growth rate. Hence marginal productivity is given by

$$F_k = b\left(\frac{Y}{K}\right)^{1+\phi}$$

Substituting into (1.2) yields

$$\frac{C_t}{P_t} = (1-\tau_t) b \left(\frac{Y_t}{K_{t-1}}\right)^{1+\phi}$$

In a frictionless world, this expression yields the optimal capital stock K^*

$$K^* = Y_t b^{\sigma} \left(\frac{C_t / P_t}{1-\tau_t}\right)^{-\sigma} \quad (1.3)$$

where σ is the elasticity of substitution given by $\sigma = 1/(1+\phi)$ and P_t is the price of output.

Instead of $\left(\frac{C_t / P_t}{1-\tau_t}\right)^{-\sigma}$ we use a broader expression for the user cost derived in Hall and Jorgenson[10] given by

$$C_t = q_t\left(r_t + \delta - \frac{\dot{q}_t}{q_t}\right)(1-\gamma_t - z_t) \tag{1.4}$$

where δ is the rate of depreciation, r_t is the real return faced by investors, and q_t is the price of investment.

Our goal is to examine the statistical relation defined in (1.3) between the user cost, C_t, and the equilibrium stock of capital, K^*, where the user cost is defined in (1.4).

b) Co-integration

We now turn to briefly reviewing the econometric techniques used in this analysis. The relationship given in (1.3) defines the equilibrium stock of capital. In logarithmic terms (1.3) can be expressed, using lower case to represent logs, as

$$k^* = \gamma + \alpha y_t - \beta(c_t / p_t) \tag{1.5}$$

where $\gamma=\sigma\ln(b)$ is a constant. The effect of taxes will be incorporated into the price measure so that all prices are pre tax. The neo-classical theoretical model presented above suggests that the expected value of α would be 1.0. In other words, for a given relative user cost of capital the capital-to-output ratio should remain constant. This is an important element of the theoretical model, rarely respected in empirical analysis, to which we will return later in this paper. An estimate for β gives the estimate of the elasticity of capital with respect to user cost. In the neoclassical world, y_t is taken to be exogenous by assumption because output is viewed as a consequence of past investment decisions. A potential difficulty with this formulation is that output may not in fact be exogenous.

The assumption in the macro-econometric literature is that K^* is the desired level of capital but, because of adjustment costs or delivery lags, this optimal stock cannot be achieved immediately. This target K^* is assumed to follow some stochastic process and investment is a process of partially adjusting towards this optimal stock K^*. The theoretical incongruence is that the empirical assumption of moving towards K^* does not match the assumption of no adjustment cost in deriving the estimating equation, i.e. in obtaining equation (1.2).[11]

If the actual capital stock, given by K, is always moving towards K^*, then the difference between the desired and the actual capital stock should be transitory, i.e.

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[10] Hall and Jorgenson (1967).

[11] Newer literature, summarized in Caballero (1999), has been more explicit in modeling this adjustment process, including explicit modeling of the adjustment process, lumpiness of investment and irreversibilities.

$$K = K^* + \varepsilon$$

where ε is some stationary residual. Substituting into (1.5) yields

$$k_t = \gamma + \alpha y_t - \beta(c_t / p_t) + \varepsilon \qquad (1.6)$$

In theory therefore we believe that (1.6) is a long-run equilibrium relationship. However, when empirically estimating a relationship between I(1) variables there is a fear that the results may be spurious. We therefore exploit the techniques of cointegration to show there is a link between integrated processes and steady-state equilibrium. Cointegration implies that there is an equilibrium relationship between the variables except for a stationary, finite variance disturbance even though the series themselves are non-stationary and have infinite variance.[12]

c) Error-Correction Model

If the series are co-integrated then there is support for believing that y_t, c_t and k_t have an equilibrium relationship. The ensuing difficulty is to relate the statistical relationship between these variables without losing information valuable to the econometrician. Differencing data would result in such a loss because we would lose information stemming from accepting (1.3) as a non-stochastic equilibrium relationship. The technique of error-correction models was developed to deal with this situation.

If (1.6) is a stochastic relationship of y_t, c_t/p_t and k_t then the extent to which these variables diverge will reflect only the stochastic nature of the data and so (1.6) will simplify to (1.3) in steady state. With such a relation between y, c/p and k, we can specify the dynamic adjustment process as an autogregressive-distributed lag of length 1 (for illustrative purposes),

$$k_t = \alpha_1 y_t - \beta_1 (c_t / p_t) + \alpha_2 y_{t-1} - \beta_2 (c_{t-1} / p_{t-1}) + \gamma k_{t-1} + \nu_t$$

which is a more general form of (1.6). Rearranging yields

$$k_t - k_{t-1} = \alpha_1 (y_t - y_{t-1}) - \beta_1 (c_t / p_t - c_{t-1} / p_{t-1}) + (\alpha_2 - \alpha_1) y_{t-1} - (\beta_2 + \beta_1)(c_{t-1} / p_t) + (\gamma - 1) k_{t-1} + \nu_t$$
$$\Delta k_t = \alpha_1 \Delta y_t - \beta_1 \Delta (c_t / p_t) + (\alpha_2 - \alpha_1) y_{t-1} - (\beta_2 + \beta_1)(c_{t-1} / p_{t-1}) + (\gamma - 1) k_{t-1} + \nu_t$$

However this equation also needs to be consistent with the equilibrium relation in (1.5) so restricting $\zeta > 0$ to the following

[12] Granger and Engle (1987).

$$\zeta = \frac{\alpha_2 - \alpha_1}{\alpha}$$

$$\zeta = \frac{\beta_1 + \beta_2}{\beta}$$

$$\zeta = 1 - \gamma$$

yields

$$\Delta k_t = \alpha_1 \Delta y_t - \beta_1 \Delta(c_t / p_t) - \zeta(k_{t-1} - \alpha y_{t-1} + \beta(c_{t-1} / p_{t-1})) + v_t \qquad (1.8)$$

which is the error-correction model advanced in by James Davidson(1978)[13] In the error correction model, the overall pattern for capital, k_t, is governed by an equilibrium process in the bracketed term from (1.5). Any prior-period disequilibrium, given by $k_{t-1} - \alpha y_{t-1} + \beta(c_{t-1} / p_{t-1})$, is corrected over time. For example, if the actual capital stock is below its desired level in the previous period, i.e. $k_{t-1} < \alpha y_{t-1} - \beta(c_{t-1} / p_{t-1})$, then capital will revert upward towards its desired level in this period. A fraction ζ of this gap is closed each period so that ζ measures the responsiveness of capital to the deviation from equilibrium in the previous period. This error correction specification encompasses the partial adjustment mechanism.[14]

Given that we presuppose that (1.5) is an equilibrium, it follows that (1.5) must represent a stable path for capital. It could therefore be argued that a restriction α=1, should be imposed *a priori*.[15] These relationships can be exploited to obtain short and long-term effects. The parameters α_1 and β_1 capture the sort-term impacts on capital of output and the relative cost.

d) Moving to Gross Investment

A potential difficulty with the above formulation is measurement error in the data on capital, which will be discussed in greater detail in the next section. To try to address this particular problem we use gross investment instead of capital stock. If the capital stock accumulates according to the relation

$$K_{t+1} = (1 - \delta)K_t + I_t$$

where I_t is gross investment, then dividing by K_t yields

$$\frac{\Delta K_t}{K_t} = \frac{I_t}{K_t} - \delta$$

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[13] See also Nickell (1985).

[14] See Representation Theorem in Granger and Engle (1987).

[15] Hence, for example, a restriction of a constant capital-output ratio is imposed through an error correction term, $\zeta(k_{t-1} - y_{t-1})$ in Bond et al. (2003).

so that in equilibrium ($\Delta K_t/K_t=g$), $I_t = (g+\delta)K_t$. This relation suggests that over the long run, the capital stock and gross investment should be determined by the same factors and hence that the capital stock, *k*, can be replaced by gross investment, *i*, in (1.6) and (1.8).

A further econometric concern with using capital is that valid (i.e. non-spurious) regressions rely on the data for each series being integrated of the same order. In our case, this requirement demands that output, user cost and capital all be integrated of order 1. As is seen in the results section, capital is I(2) whereas gross investment is I(1) which appears to contradict the accumulation identity just given above. However, it has been shown that this accumulation rule does not hold using Fisher-chain data and therefore it is possible for the identity and the results of the unit root tests to be different.

e) Estimating Equations

To summarize, our estimating equations are, firstly, the potentially cointegrating relationship from (1.6), where we use investment rather than capital,

$$i_t = \gamma + \alpha.y_t - \beta(c_t - p_t) + \varepsilon \tag{1.9}$$

So that more of the short-run disequilibria factors are taken into account, we also include a measure of the GDP gap in the error correction form from (1.8),

$$\Delta i_t = \alpha_1 \Delta y_{t-1} - \beta_1 \Delta(c_{t-1} / p_{t-1}) + \phi GDPgap_{t-1} - \zeta(i_{t-1} - \alpha y_{t-1} + \beta(c_{t-1} / p_{t-1})) + \nu_t \tag{1.10}$$

As mentioned previously, in formulating this problem we arbitrarily chose a lag of one period. Our estimated results below show results using two lagged periods.

We also believe that investment must be on a stable path, implying that $\alpha=1$. If α were found to be significantly different from 1 then we would estimate regressions with an output elasticity imposed at 1, i.e. $\alpha = 1$,

$$i_t = \gamma + y_t - \beta(c_t - p_t) + \varepsilon \tag{1.11}$$

and

$$\Delta i_t = \alpha_1 \Delta y_t - \Delta(c_t / p_t) + \phi GDPgap - \zeta(i_{t-1} - y_{t-1} + \beta(c_{t-1} / p_{t-1})) + \nu_t \tag{1.12}$$

3. Econometric Difficulties

The use of macroeconomic data to undertake this analysis is recognized to be fraught with difficulties, which have been highlighted in various papers. [16] This section summarizes some of the main difficulties.

We examine some, though not all, of these concerns in our estimation approach.

a. Assumptions about dynamics, in particular the nature of adjustment costs and financing constraints

The dynamics of the movement in investment from one equilibrium to another are left unmodeled in this formulation. Further complications may arise through aggregating investments with different adjustment speeds. The failure to model these aspects in micro-econometrics has been criticized because the micro data does exhibit discrete jumps, i.e. adjustments costs may be fixed not variable.[17] Fuller modeling of adjustment costs and financing constraints may yield more precise estimates.[18]

However, it is unclear if these aspects should be introduced into macro-estimation. Hamermesh(1989)'s study also finds that smooth adjustment of investment is a feature of macro data. Furthermore aggregating discrete investment decisions may lead to a smooth pattern of change for aggregate data.[19]

b. Variations may reflect transitory rather than permanent changes[20]

This difficulty arises because a mixture of permanent and transitory shocks drives aggregate data. Firms respond more to permanent shocks rather than to transitory shocks because of adjustment costs: it is not worth their while to respond to every movement. But with permanent shocks agents' conditional expectations are altered.[21]

In our estimations, investment is regressed on output and the user cost of capital. If the data on one of these regressands is driven more by permanent shocks whereas the other exhibits shocks that are mean reverting (i.e. transitory) then the elasticity to the former will be greater than the latter. For example, in their analysis of Japanese data, Nobuhiro Kiyotaki and Kenneth D. West find that output shocks are persistent and cost of capital shocks are mean reverting.[22] They attribute their finding of a low elasticity for the user cost of capital and a high elasticity of capital with respect to output to this finding.

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[16] As in, for example, Chirinko et al.(2002).
[17] Hamermesh (1989).
[18] See, for example, Caballero and Engle (1992).
[19] King and Thomas (2000).
[20] This point seems to have been made originally with respect to investment by Eisner(1967).
[21] Technically, let X_t be a difference-stationary sequence and E_t the conditional expectation taken with respect to the information set in period t. Hence the shock η_t is said to have permanent effects on the level of X_t if $\lim_{h\to\infty} \partial E_t(X_{t+h})/\partial \eta_t \neq 0$. See Gonzalo and Ng (2001).
[22] Kiyotaki and Kwest (1996).

c. The supply curve may be upward sloping

A concern with investment tax credits is the possibility that the producers of capital goods would increase their prices.[23] Further work by Hassett and Hubbard(1999) has cast doubt on whether this is a serious problem. We use Canadian data so the use of policies to encourage investment is unlikely to change the world price of investment goods.[24]

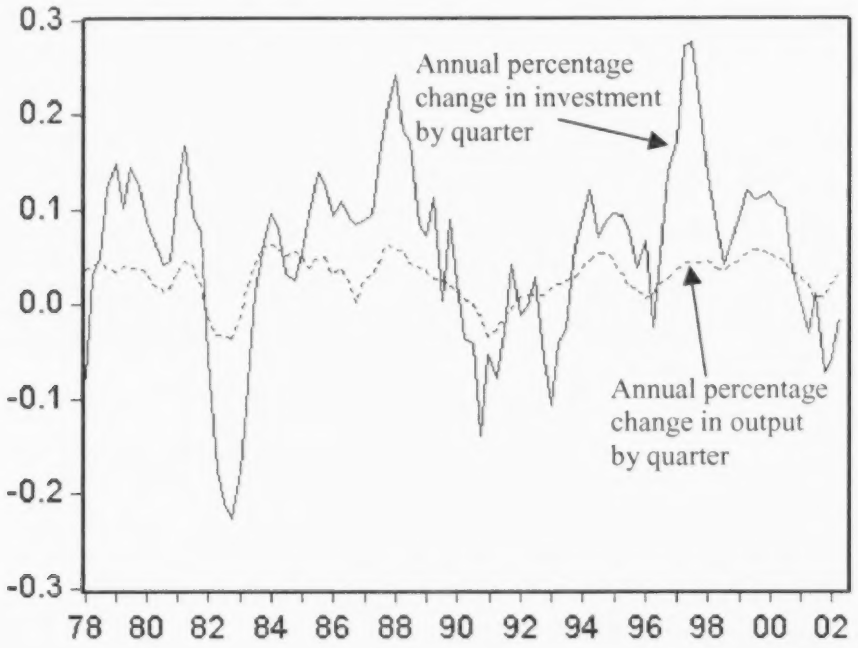
d. Endogeneity of interest rate

As mentioned before, the neo-classicists view output as a result of capital decisions taken by firms and output is therefore not endogenous. However, a problem initially highlighted by Hall(1979,1993) is that both output and the interest rate are endogenous variables and are likely to respond positively to investment. In particular, if there were an increase in the size of the economy (e.g. through a demand shock) then investment would likely increase but also interest rates would increase as the central bank tried to cool the economy. This close movement of output and investment can be seen in Figure 1, which led to the initial accelerationist interpretation of investment (i.e. that output not user cost mattered for investment). This endogeneity leads to a downward bias in the user cost coefficient and an upward bias in the coefficient on output.

[23] See, for example, Goolsbee (1998).

[24] Although this possibility of an upward-sloping supply curve raises econometric concerns, it is not obvious that an increase in the price of capital goods is necessarily welfare worsening from the economic point of view. Increased profits for new and innovative equipment would give firms increased incentive to develop new products, which may contribute to economic growth. When new goods are developed they will have a mark-up over marginal cost irrespective of whether they are produced in a small open economy or not (assuming perfect patent protection).

Figure 1: Log of Canadian Real GDP and M&E Investment (1978-2002)



Jacques Mairesse, Bronwyn Hall and Benoît Mulkay(1999) examine micro data of firm investment behaviour where the same issue arises when cash flow is substituted for output. They use instruments in combination with a GMM estimation technique to try to control for endogeneity. They find that cash flow no longer enters the firm-level investment equation (showing that there was an endogeneity problem) but that the coefficients are too imprecisely estimated to be reliable. Their results suggest that although endogeneity is a problem no useful way has been found to circumvent it.

Again referring to Figure 1 we see that the variance of investment is far greater than that of output and the two series are significantly correlated suggesting that output has a somewhat magnifying effect on investment. It is therefore not surprising that our results exhibit excess sensitivity of investment to output. To address this potential endogeneity problem in or analysis we require results to be consistent with a long-run equilibrium through imposing investment's elasticity with respect to output to be equal to one in the long run.

e. Measurement error

There are numerous difficulties in obtaining accurate measures of the capital stock. One difficulty in particular for its measurement may be in measuring the written-down value of past capital, i.e. through measuring depreciation. As mentioned in the previous section, we try to address this concern by estimating the impact of changes in relative user cost on gross investment, which we believe to be more precisely measured.

Although mismeasurement in general has been a preoccupation of econometricians for a while, it seems that Austan Goolsbee(2000) was the first to address this issue with respect to estimating the elasticity of investment. Specifically, he was concerned with measurement error in the user cost. After correcting for measurement error he found an elasticity estimate close to 1. In our analysis we are assuming there is no measurement error in the user cost.

f. Aggregation error

Aggregation error arises because investments with differing characteristics are aggregated. Within the context of investment, these characteristics may include different adjustment speeds, depreciation rates, tax treatment, etc. Further there may be permanent shocks to the price of some components and transitory shocks to others, which would lead to the problem highlighted above. As pointed out by Thomas Stoker(1984), the potential lack of a correspondence between microeconomic behaviour and estimated relations between averaged data presents some difficulties in interpreting parameters estimated with aggregate data as being the behavioural parameters of individuals or firms.[25] Working in the opposite direction, Tevlin and Whelan(2003) point out that the failure to account for the larger share of computers in equipment spending led to difficulties in explaining the behaviour of aggregate investment in the U.S. during the 90s. Computers have a higher depreciation rate and purchases of computers are more responsive to the user cost of capital.

[25] See also some discussion in Koebel (2002).

4. Data and Results

a. The Data

Data are from the CEFM (Canadian Economic and Fiscal Model) database, which primarily consists of data from the national accounts division of Statistics Canada. Our data go from the first quarter of 1978 to the second quarter of 2002, while the core of our analysis uses data from 1984 onwards. Results for non-residential construction provide results that are difficult to explain. Hence we concentrate our analysis on M&E and all data will refer to M&E.[26]

The series used are the user cost of capital for M&E, M&E investment, output, and the price of output. Chain dollar series are used in the case of output, capital stock and investment. User cost of capital is calculated from (1.4) and involves many components such as historic tax rates, tax credits and interest rates which come from other portions of the CEFM database.[27] Unless otherwise noted, all analysis is conducted in natural logs. Further details regarding the data used are in Appendix A.1.

As mentioned above we want to ensure our data reflects a period in which economic agents would regard price changes as permanent. This amounts to selecting a user cost sample that contains a consistent trend. Looking at Figure 2 we see that the log of the user cost is falling consistently from the mid-80's to late 90's. We chose the sample 1984:1 to 2002:2 for aggregate user cost because it contains the most pronounced downward trend and is still large enough to provide meaningful results. We conducted sensitivity analysis and found that both our cointegration results and long-run elasticity estimates were not responsive to changes in the starting date. The details of this analysis can be found in Appendix B.1.

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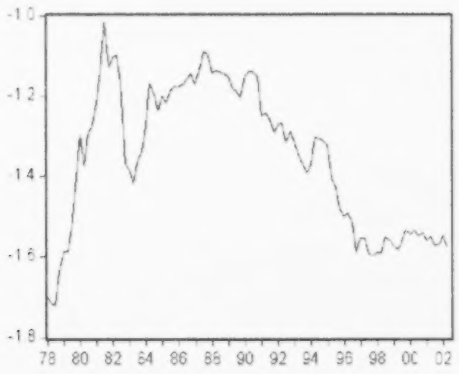
[26] We have estimated identical regressions using non-residential construction data and results are available upon request. Since no convincing economic model for non-residential construction investment exists it is perhaps not surprising that our parameter estimates were often insignificant and of the wrong sign and the overall fit of these models was poor.

[27] The real interest rate used throughout is the average of ten industrial bonds. A potential problem with this formulation is that future tax credits arising from current investment will be obtained with certainty because they are essentially commitments from the government. Consequently the risk-free rate should be used to discount the net present value of these allowances. See Summers (1987). A caveat is that if firms experience tax exhaustion (i.e. they pay no taxes in the year) then no benefit would be obtained from having tax credits.

Figure 2: Log of the Relative User Cost of M&E



b. Estimation Procedure

Before any regressions were estimated we conducted augmented Dickey-Fuller[28] and KPSS[29] unit root tests on all of the series. Our results show that all series are integrated of order 1, except for capital, which is integrated of order 2. Detailed test statistics, test descriptions, and significance levels for all unit root tests are in Appendix A.

The estimation procedure we employ consists of estimating regressions of two types. Using OLS estimation techniques we first estimate the long run elasticities represented by the parameters α and β in equation (1.9). Since our unit root tests show that all of the variables in this regression are integrated of order 1, we test for cointegration to ensure our findings are not spurious.[30] If we find cointegration using the Engle-Granger[31] or Johansen tests[32], OLS estimation is valid and our coefficient estimates are super consistent.[33] With the estimation of the long-run relationship complete we estimate the error correction model described by equation (1.10). All variables in the error correction model are integrated of order zero so we need not be concerned with the spurious regression problem. All of these procedures are repeated for the sub components of total machinery and equipment and again for the cases in which we set the output elasticity to 1.

c. Estimation Results

Estimates of the long-run relationship between investment, output and the user cost of capital are shown in Table 1 for the cases with and without the output elasticities

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[28] Dickey and Fuller (1979).
[29] Kwiatkowski et al. (1992).
[30] The problem of a spurious regression is that of finding a significant relationship between variables when in fact none exists. In an OLS regression this means that t-statistics used to judge significance will be biased upwards and thus we are more likely to falsely reject the null hypothesis of the parameter being equal to zero. Granger and Newbold (1974).
[31] Engle and Granger (1987).
[32] See Johansen (1988, 1991).
[33] James H. Stock (1987).

restricted to 1. Without restricting the output elasticity we find statistically significant long-run elasticities between investment and output but much weaker results with respect to the user cost of capital. The elasticity of investment with respect to user cost is 0.14 but is of the wrong sign. The Johansen cointegration test shows significant evidence of cointegration.[34]

Table 1: Long-run Elasticity Estimates (1984:1 to 2002:2)

	Machinery and Equipment (Freely Estimated)	Machinery and Equipment (Output Restricted to 1)
constant	-23.84 ***	-4.09 ***
	(0.000)	(0.000)
c_t / p_t	0.14 *	-0.97 ***
	(0.098)	(0.000)
y_t	2.56 ***	1
	(0.000)	
R-squared	0.96	0.63
	Cointegration Results	
Engle-Granger	-2.72	-3.40 **
Johansen LM	39.24 **	11.40

p-values in parentheses
*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

A concern highlighted in the first column of Table 1 is that the coefficient on output is greater than 1. This result shows an excess sensitivity of investment to output, suggesting an explosive path for investment as well as highlighting potential endogeneity problems.[35]

The second column of Table 1 shows the long-run elasticity estimates when the coefficient on output is restricted to a value of 1. Our estimate of the price elasticity of investment is now close to 1, significant at the 1% level, and approximates those

[34] We also estimated identical regressions using non-residential construction data. Since no convincing economic model for non-residential construction investment exists it is perhaps not surprising that our parameter estimates were often insignificant and of the wrong sign and the overall fit of these models was poor.

[35] When initially faced with a potential endogeneity problem we performed an IV estimation to see if it would help. Using lagged output and U.S. GDP as instruments we still found a small user cost elasticity and large output elasticity.

estimates found using micro panel data estimation techniques. The results of the Engle-Granger test support the hypothesis of cointegration.

Figure 3 shows the actual path followed by investment and the path predicted by our estimates when there is no restriction on the output elasticity. The difference between these two paths is the residual shown in the bottom portion of Figure 3. There are prolonged periods where investment is above and below the expected path but it tends to return to the expected path over time.

Figure 3: Long-Run M&E investment - actual and predicted path, residual freely estimated

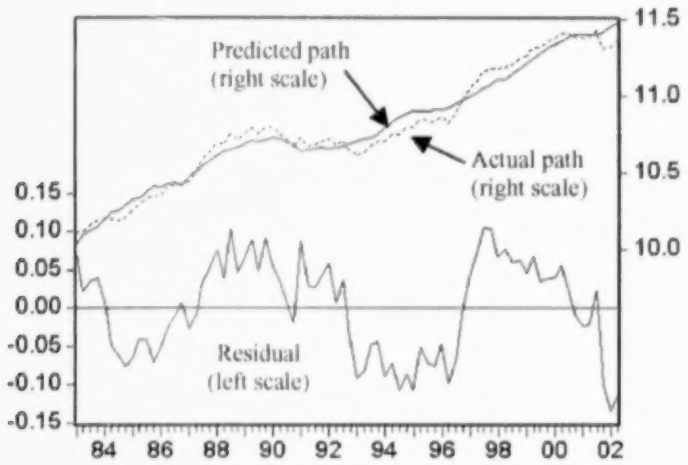
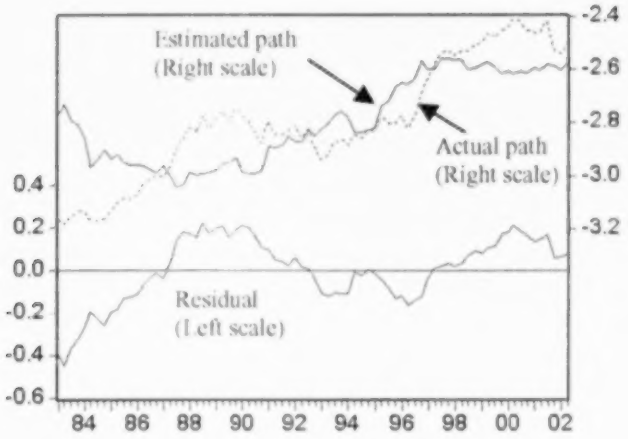


Figure 4 shows the same information but with the coefficient on output elasticity restricted to 1.0. There are obviously larger divergences between the actual and predicted paths, when compared to Figure 3, because the role of output in explaining investment is reduced. But the residual displays the same overall pattern and changes sign in roughly the same places. Actual investment was much higher than that predicted by the estimated model over 1998-2000 suggesting that investment was not on a sustainable path at this time.

The results of estimating the error correction model from equation (1.10) and equation (1.12) are displayed in Table C.1 in Appendix C. The estimate of the M&E adjustment parameter, ζ, with unrestricted output response is statistically significant but small. However, the coefficient is positive indicating an explosive path for investment growth: a prior-period disequilibrium will be exacerbated in the current period. When we restrict the long-run elasticity of output to 1 the adjustment parameter has the appropriate sign but the coefficient estimate is statistically insignificant.

Figure 4: Long-Run M&E Investment – actual and estimated path and residual, with output restriction



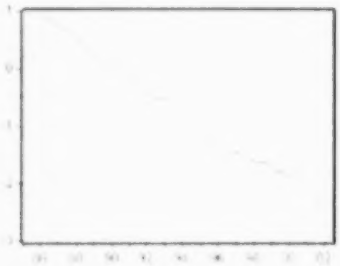
The second part of Table C.1 displays estimates of the short run dynamics. For the freely estimated investment in M&E regression we see that growth of one period lagged output has a large, positive, and statistically significant effect on the growth of investment. The growth of lagged user cost of capital, however, is statistically insignificant. When the long run coefficients on output are set to one, we do not see a large change in the significance or magnitude of the short-run estimates. The only significant short run estimate is the first lag of output. These results reinforce the idea of an excess sensitivity of investment to output.

d. Breakdown of M&E

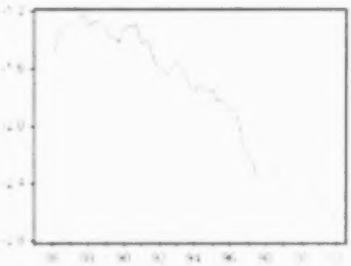
We now decompose M&E into its component parts and time series for these components are shown in Figure 5. Computers and software show a consistent downward path in their prices but telecommunication equipment and other components show a more varied path. Our expectations are therefore that falls in the relative price of computers and software will be seen as permanent inducing greater investment response and hence resulting in a larger estimate of the user cost elasticity.

It would seem that the rebound in prices for telecom equipment and other components since 1998 when married with continuing price falls for computers and software is responsible for the flattening of the user cost for aggregate M&E shown in Figure 2. This effect may distort the elasticity estimates that we obtain for aggregate M&E and so aggregation error may be a problem that explains low elasticity estimates obtained previously.

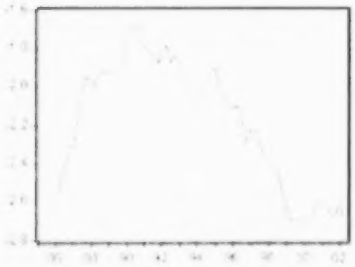
Figure 5: Relative User Cost Series for the Components of M&E (c_t/p_t)



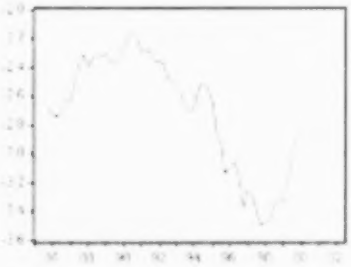
a) User Cost of Computers



b) User Cost of Software



c) User Cost of Telecom Equipment



d) User Cost of Other M&E

A difficulty in undertaking the breakdown of M&E into its components is that no data exist on the individual tax changes that each component has faced. Hence the tax series for aggregate M&E is used for each of the components. It is unlikely that this second problem is material as there was only one change in the depreciation allowances over this period and this change was likely common to all forms of M&E. However, depreciation rates are available for each asset type.

Tevlin and Whelan(2003) decompose the impact of the user cost of investment into two parts: a price effect and a non-price effect that mostly reflects changes in the tax code. A similar undertaking was done here with Canadian data. However, it was found that the most important factor in explaining the tax-change term was the change in the present value of depreciation allowances—the z in (1.4)— but, in turn, this term mostly reflected the effect of lower interest rates rather than changes in the tax system. We believe that the importance of the interest rate in both the price and non-price terms rendered the decomposition moot.

Each component of M&E is regressed independently on output, its user cost and a constant. The long-run elasticities are displayed in Table 2, along with the cointegration results for each group. Significant cointegration is found for each of the four breakdowns validating the OLS estimation. Estimation leads to large price elasticities, greater than 0.5, for computers and software, and both of these estimates are highly significant. The results are a significant improvement on the estimates obtained for aggregate M&E which were of the wrong sign. On the other hand the telecommunication equipment and other M&E regressions are very similar to those of aggregate M&E. The price elasticity estimates are significant but of the wrong sign. These results suggest that failing to obtain data that exhibits permanent price changes may be an important factor in obtaining low price elasticities.

Again, a common feature of all four long-run regressions is the high elasticity between output and investment. All of these estimates are greater than one, once again contradicting the theory.

Because of the prominence of the output elasticity, we redo the estimates again with the output elasticity fixed at 1.0. As seen in Table 3, the price elasticities more than double and become greater than one for computers and software. The price elasticity for telecommunications equipment now has the correct sign and is larger in magnitude. For all three of these regressions there is strong evidence of cointegration.

The regression for other M&E does not look so promising. We cannot find any evidence of cointegration. The elasticity between investment and the user cost is near zero and insignificant at the 10 percent level.

Table 2: Long-run Elasticity Estimates (1986:1-2002:2) ICT Breakdown, Freely Estimated

	Computers	Software	Telecomm. Equipment	Other M&E
Constant	-60.53 ***	-28.71 ***	-36.40 ***	-4.86 ***
	(0.000)	(0.000)	(0.000)	(0.007)
y_t	5.00 ***	2.65 ***	3.29 ***	1.15 ***
	(0.000)	(0.000)	(0.000)	(0.000)
c_t / p_t	-0.55 ***	-0.59 ***	0.11 *	0.07 ***
	(0.000)	(0.001)	(0.097)	(0.086)
R-squared	0.99	0.89	0.92	0.61
Cointegration Results				
Engle-Granger	-2.09	-1.45	-3.09	-2.17
Johansen LM	25.30 **	43.1 ***	39.42 **	42.3 ***

p-value in parentheses
*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

Table 3: Long-run Elasticity Estimates (1986:1-2002:2) ICT Breakdown, Output Restricted to 1

	Computers	Software	Telecomm. Equipment	Other M&E
constant	-6.41 ***	-7.03 ***	-6.58 ***	-2.85 ***
	(0.000)	(0.000)	(0.000)	(0.000)
c_t / p_t	-1.05 ***	-1.02 ***	-0.54 ***	0.04
	(0.000)	(0.000)	(0.000)	(0.119)
y_t	1	1	1	1
R-squared	0.96	0.83	0.36	0.03
Cointegration Results				
Engle-Granger	-1.61	-1.17	-4.47 ***	-2.34
Johansen LM	25.2 ***	22.4 ***	14.3	10.92

p-value in parentheses
*** Significant at the 1% level.

Both the restricted and unrestricted decomposed regressions support the idea of aggregation error. For series with clear downward trends in the user cost of capital we get strong elasticity estimates that become even stronger when we set the response of output equal to our theoretical prior. For series with no pronounced trend we find that

investment is basically unaffected by changes in the user cost of capital. In aggregation we see a combination of these two effects. The relatively strong results we obtain for software and computers are moderated by the weaker results obtained for telecommunication equipment and other M&E. Since all three ICT components only make up a little over 30 per cent in 2002 of total nominal M&E investment, the aggregate results are weighted towards those of other M&E.

As with aggregate M&E we estimated an error correction model for all four subcomponents. Unrestricted estimates are reported in Table C.2 in Appendix C. Estimates of the adjustment parameter, ζ, have the correct sign for all components but only the estimates for telecommunications equipment and other M&E are statistically significant. The magnitude of the adjustments for telecommunications equipment and other M&E are very large at 18 per cent per quarter suggesting rapid adjustment of investment to the long-run equilibrium.

The results of estimating the error correction model when the output elasticity is restricted to 1 are shown in Table C.3 also located in Appendix C. Again, all of the adjustment parameters have the correct sign and only the estimate for software is insignificant. The magnitude of the adjustment parameter in the case of other M&E is larger than in the unrestricted case at 20 percent per quarter. This result should be treated with caution given that there was little evidence of a long-run equilibrium for this component of M&E.

The lack of significance in any of the short-run dynamic estimates reinforces the idea that investment in sub components of machinery and equipment is a long-run phenomenon. None of the growth estimates are significant, and as in the case of the aggregate M&E estimation we do not see a significant change in the estimates when we move from the unrestricted model to the restricted model.

5. Conclusions and Future Research

We have examined the relationship between investment and its user cost. Traditionally, macro-econometric estimates of the user cost elasticity are considerably lower than those found by micro-econometricians.

By limiting the extent to which investment can be on an explosive path, we find elasticity estimates that approximate those of the micro-econometric analyses. Using data from 1984 onwards, when there was a greater likelihood that agents would recognize equipment price changes were permanent, helped us to identify a stronger price effect. Using more disaggregated data further allowed us to obtain higher elasticities, as a permanent shock was more pronounced for components such as software and computers.

We suggest that the possibility of disequilibrium behaviour by investment is the result of endogeneity problems. Our work in this paper leads us to conclude that the endogeneity of output is a significant problem in obtaining a reasonable estimate of the user cost elasticity. Further research should be conducted to addressing this issue.

We believe therefore there is increasing evidence to support the argument that lowering the user cost of capital would have a significant impact on firms' investment. In particular our results suggest any potential policy initiatives should be focussed on permanent and sustainable changes in the user cost.

Bibliography

Aled ab Iorwerth, 2002, "Taxation, Machines and the Economics of Growth", *mimeo*, Dept. of Finance Canada.

Charles L. Ballard, John B. Shoven, and John Whalley, 1985, "General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States", *American Economic Review* 75, 1, pp. 128-38.

Ben S. Bernanke and Mark Gertler, 1995, "Inside the Black Box: The Credit Channel of Monetary Policy Transmission", *Journal of Economic Perspectives* 9, 4, 27-48.

Stephen Bond, Julie A. Elston, Jacques Mairesse and Benoît Mulkay, 2003, "Financial Factors and Investment in Belgium, France, Germany and the United Kingdom: A Comparison Using Company Panel Data", *Review of Economics and Statistics* 85, 1, 153-165.

Ricardo J. Caballero, 1999, "Aggregate Investment", pp. 813-862 in eds. John B. Taylor and Michael Woodford, *Handbook of Macroeconomics vol. 1B* , Amsterdam; New York and Oxford: Elsevier Science, North-Holland.

Ricardo J. Caballero and Eduardo M.R.A. Engle, 1992, "Beyond the Partial-Adjustment Model", *American Economic Review* 82, 2, 360-364.

John Campbell and Pierre Perron, 1991, "Pitfalls and Opportunities: What Macroeconomists Should Know About Unit Roots," *NBER Macroeconomics Annual*, Vol. 6, eds. O.J. Blanchard and S. Fischer, Cambridge: MIT Press, 141-201.

Robert S. Chirinko, 1993, "Business Fixed Investment Spending: Modeling Strategies, Empirical results and Policy Implications", *Journal of Economic Literature* 31, 1875-1911.

Robert S. Chirinko, 2002, "Corporation Taxation, Capital Formation and the Substitution Elasticity between Labour and Capital", *National Tax Journal* 55, 2, 339-355.

Robert S. Chirinko, Steven M. Fazzari and Andrew P. Meyer, 2002, "That Elusive Elasticity: A Long-Panel Approach to Estimating the Price Sensitivity of Business Capital", *mimeo*.

Jason G. Cummins, Kevin A. Hassett and R. Glenn Hubbard, 1994, "A Reconsideration of Investment Behaviour Using Tax Reforms as Natural Experiments", *Brookings Papers on Economic Activity No. 2*, pp. 1-59.

James E.H. Davidson, David F. Hendry, Frank Srba and Stephen Yeo, 1978, "Econometric Modelling of the Aggregate Time-Series Relationship Between Consumers' Expenditure and Income in the United Kingdom", *Economic Journal* 88, 661-692.

Russell Davidson and James G. MacKinnon, 1993, *Estimation and Inference in Econometrics* New York: Oxford University Press,.

Alain DeSerres, 1995, "The Review of the Investment Sector in CEFM: An Error-Correction Approach", *mimeo*, Department of Finance Canada.

D.A. Dickey and W.A. Fuller, 1979, "Distribution of the Estimators for Autoregressive Time Series With a Unit Root," *Journal of the American Statistical Association* 74, 427-431.

Robert Eisner, 1967, "A Permanent Income Theory of Investment: Some Empirical Explorations", *American Economic Review* 57, 3, 363-390.

Jesus Gonzalo and Serena Ng, 2001, "A Systematic Framework for Analyzing Dynamic Effects of Permanent and Transitory Shocks", *Journal of Economic Dynamics and Control* 25, 1527-1546.

Austan Goolsbee, 1998, "Investment Tax Incentives, Prices, and the Supply of Capital Goods", *Quarterly Journal of Economics* 113, 1, 121-148.

Austan Goolsbee, 2000, "The Importance of Measurement Error in the Cost of Capital", *National Tax Journal* 53, 2, 215-228.

Clive Granger and Robert Engle, 1987, "Cointegration and Error Correction: Representation, Estimation and Testing", *Econometrica* 55, 2, 251-276.

C.W.J Granger and P. Newbold, 1974, "Spurious Regressions in Econometrics," *Journal of Econometrics*, 2, 111-120.

Luigi Guiso, Anil K. Kashyap, Fabio Panetta and Daniele Terlizzese, 2002, "How Interest Sensitive is Investment? Very (when the data are well measured)", http://www.nber.org/~confer/2002/si2002/guiso.pdf.

Robert E. Hall, 1979, panel discussion, *Brookings Papers on Economic Activity No. 1*, pp. 122.

Robert E. Hall, 1993, panel discussion, *Brookings Papers on Economic Activity No. 1*, pp. 345.

Robert E. Hall and Dale W. Joregenson, 1967, "Tax Policy and Investment Behavior", *American Economic Review* , 57, 3, 391-414.

Daniel S. Hamermesh, 1989, "Labor Demand and the Structure of Adjustment Costs", *American Economic Review* 79, 4, 674-689.

Kevin A. Hassett and R. Glenn Hubbard, 1997, "Tax Policy and Investment", in Alan J. Auerbach, ed., *Fiscal Policy: Lessons from Economic Research* Cambridge: MIT Press.

Kevin A. Hassett and R. Glenn Hubbard. 1999, "Are Investment Incentives Blunted by Changes in Prices of Capital Goods?",*International Finance* 1, 1, 106-125.

Soren Johansen, 1988, "Statistical Analysis of Cointegration Vectors," *Journal of Economic Dynamics and Control* 12, 231-254.

Soren Johansen, 1991, "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models," *Econometrica*, 59 1551-1580.

Robert G. King and Julia K. Thomas, 2000, "Partial Adjustment without Apology", *mimeo*.

Nobuhiro Kiyotaki and Kenneth D. West, 1996, "Business Fixed Investment and the recent Business Cycle in Japan" in Ben S. Bernanke and Julio Rotemberg eds., *NBER Macroeconomics Annual 1996*, Cambridge: MIT Press.

Betrand M. Koebel, 2002, "Can Aggregation Across Goods Be Achieved by Neglecting the Problem? Property Inheritance and Aggregation Bias", *International Economic Review* 43, 1, 223-255.

D. Kwiatkowski, P.C.B. Phillips, P. Schmidt and Y. Shin, 1992, "Testing the Null Hypothesis of Stationarity Against the Alternative of a Unit Root", *Journal of Econometrics* 54, 159-178.

Yanjun Liu, 2001, "Fisher Aggregation and Subtraction," *mimeo*, Department of Finance

Yanjun Liu and Bing-Sun Wong, 2001, "Stock-Flow Accumulation Rules with Chain Fisher Data," *mimeo*, Department of Finance.

Jacques Mairesse, Bronwyn Hall and Benoît Mulkay, 1999, "Firm-Level Investments in France and the United States: An Exploration of What We Have Learned in Twenty Years", *Annales d'Economie et de Statistique*, 55-56, 27-67.

Stephen Nickell, 1985, "Error Correction, Partial Adjustment and all That: An Expository Note", *Oxford Bulletin of Economics and Statistics* 47, 2, 119-129.

James H. Stock, 1987, "Asymptotic Properties of Least Squares Estimators of Cointegrating Vectors," *Econometrica*, 55, 1035-1056.

Thomas M. Stoker, 1984, "Completeness, Distribution Restrictions, and the Form of Aggregate Functions", *Econometrica* 52, 4, 887-908.

Lawrence H. Summers, 1987, "Investment Incentives and the Discounting of Depreciation Allowances", in Martin Feldstein, ed., *The Effects of Taxation on Capital Accumulation* Chicago: University of Chicago Press.

Stacey Tevlin and Karl Whelan, 2003, "Explaining the Investment Boom in the 1990s", *Journal of Money, Credit and Banking* 35, 1, 1-21.

Appendix A

A.1 Data Sources

This section describes the data used in the regression analysis as described by equation (1.9) and (1.10). It also describes, in greater detail, the method by which aggregate M&E was broken into its various components.

Total Machinery and Equipment

Quarterly Fisher-chained investment was obtained from the Statistics Canada. These data are from the business sector only and thus exclude all capital related to the public sector. Depreciation rates were calculated by dividing current year depreciation by past end-year net capital stock using the hyperbolic (delayed) method.[36] We used a cubic spline function to extrapolate a quarterly depreciation time series from the annual data. Output is defined as the total-economy real Fisher-chained GDP.

Components of Machinery and Equipment

We obtained quarterly investment data from the National Accounts division for telecommunications equipment, software, and computer and other office equipment which are typically labelled as the information and communication technology equipment components of total machinery equipment. We obtained the other machinery and equipment series from Bing-Sun Wong of the Economic Analysis and Forecasting Division.[37] Deprecation rates for these sub-categories are calculated in the same manner as the depreciation rates for total machinery and equipment.

A.2 Unit Root and Cointegration Tests

Two standard unit root tests were performed; the augmented Dickey-Fuller (ADF) test and a test developed by Kwiatkowski, Phillips, Schmidt and Shin (the KPSS test). Stationarity is the null hypothesis of the KPSS test while non-stationarity is the null of the ADF test. Classical hypothesis testing is carried out in a way that ensures the acceptance of the null hypothesis unless there is strong evidence against it. Since the KPSS and ADF tests have opposite null hypotheses, we present the results of both tests and deem the conclusion of a unit root consistent if we reject the null of the former and fail to reject the null of the later.

The results of both of these tests for total M&E and non-residential construction as well as the components of M&E are shown in Table A.1 and Table A.2.

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[36] Because of the properties of chain Fisher data this method of calculating the depreciation rate only approximates the true underlying aggregate depreciation rates. Liu and Wong (2001) find that this approximation matches depreciation rates calculated using the Laspeyres index quite closely.

[37] See Liu (2001).

Augmented Dickey-Fuller Test[38]

The general form of the ADF test regression is

$$\Delta_1 y_t = \mu + \delta t + \rho y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta_1 y_{t-i} + \varepsilon_t$$

where y is the series under test, $\mu + \delta t$ is the deterministic trend component and p represents the number of lagged dependent variables included in the regression.

The choice of which deterministic components to include in this regression is important since a misspecification could lead, falsely, to a non-rejection of the unit root hypothesis.[39] The appropriate deterministic components to include in our regressions were determined by visual inspection.

Lagged dependent variables are included to eliminate any serial correlation in the residuals. Including too many lags increases the number of parameters being estimated and thereby reduces the degrees of freedom, which ultimately reduces the power of the test. Not including enough lag terms may reduce the ability to accurately estimate the ADF-test statistic and its standard error because the actual error process is not being captured. We used three different methods to estimate p. The first two involve selecting the lag length that minimizes Aikakie and Schwarz information criteria. The third method involves running the ADF regression starting with a relatively long lag length and subsequently reducing this number by eliminating lags deemed insignificant by simple t-tests evaluated at appropriate critical values. Sufficiently long starting values are chosen somewhat arbitrarily but are typically related to the frequency of the data (e.g. multiples of 4 for quarterly data). We used starting values of 12 for the M&E and non-residential construction series and starting values of 8 for the ICT components. When the chosen lag length differed across selection methods we used the one selected by the paring down approach.

Although the test statistic is the simple t-test on the ρ coefficient in the above equation, the critical values used to determine significance are non-standard. We used aysmptotic critical values found in Davidson and MacKinnon(1993), regarded as improvements on the original critical values calculated by Dickey and Fuller.

KPSS Test[40]

This consists of estimating the auxiliary regression

$$y_t = \mu + \delta t + \varepsilon_t$$

[38] Dickey and Fuller (1979).
[39] Campbell and Perron (1991).
[40] Kwiatkowski et al. (1992).

where y is the series under test, and $\mu + \delta t$ is the deterministic trend component. The test statistic is then

$$\hat{\eta} = n^{-2}(s^2(l))^{-1}\sum_{t=1}^{n} S_t^2$$

where n is the sample size, $s^2(l)$ is the long run variance and S_t is the partial sum of the residuals from the auxiliary equation. Unlike the ADF regression there is no lag-selection issues to consider.[41] This test statistic is also distributed non-standard so in order to judge significance we used the critical values created by Kwiatkowski et al. (1992).

[41] There was no consideration in Kwiatkowski et al. (1992) of adding any lag dependent variables in the auxiliary regression although modern time series packages allow for this option using the pared down approach. We followed the methodology used in the original paper.

Table A.1: Unit Root Tests

	Aggregate		M & E		Non-Residential Construction	
	ADF	KPSS	ADF	KPSS	ADF	KPSS
Capital Stock						
Level	-1.82	3.88***	-1.94	1.78***	-1.95	3.95***
First-Difference	-2.82	1.05***	-3.19*	1.13***	-2.55	1.19***
Second-Difference	-3.54**	0.29	-5.13***	0.33	-4.38***	0.25
Conclusion	**I(2)**	**I(2)**	**I(2)**	**I(2)**	**I(2)**	**I(2)**
Investment						
Level	-2.42	1.53***	-3.92**	0.85***	-2.24	2.75***
First-Difference	-3.54**	0.16	-4.06***	0.11	-3.52***	0.28
Second-Difference	--	--	--	--	--	--
Conclusion	**I(1)**	**I(1)**	**I(1)**	**I(1)**	**I(1)**	**I(1)**
Output						
Level	-2.42	3.26***	--	--	--	--
First-Difference	-3.70***	1.36***	--	--	--	--
Second-Difference	--	0.01	--	--	--	--
Conclusion	**I(1)**	**I(2)**	--	--	--	--
User Cost of Capital						
Level	-2.08	1.35***	-1.99	1.49***	-3.03	0.94***
First-Difference	-4.70***	0.16	-4.67***	0.16	-4.57***	0.17
Second-Difference	--	--	--	--	--	--
Conclusion	**I(1)**	**I(1)**	**I(1)**	**I(1)**	**I(1)**	**I(1)**

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

ADF critical values are from pp. 708, Davidson and MacKinnon (1993).

KPSS critical values are from , pp. 166, Kwiatkowski et al.(1992).

Table A.2 Unit Root Tests

	Computers		Software		Telecommincations Equipment		Other Machinery and Equipment	
	ADF	KPSS	ADF	KPSS	ADF	KPSS	ADF	KPSS
Investment								
Level	-1.62	1.02***	-0.45	1.26***	-2.39	0.31***	-1.46	0.63***
First-Difference	-8.26***	0.11	-3.88**	0.65**	-9.65***	0.06	-7.88***	0.13
Conclusion	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
User Cost of Capital								
Level	-1.92	0.82***	-2.77	0.82***	-0.79	1.19***	-1.15	3.93***
First-Difference	-5.77***	0.15	-4.00***	0.13*	-6.40***	0.22***	-5.84***	0.26
Conclusion	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(1)	I(1)

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.
ADF critical values are from pp. 708, Davidson and MacKinnon (1993).
KPSS critical values are from pp. 166, Kwiatkowski et al. (1992).

Appendix B

B.1 Sensitivity Analysis

In our analysis we selected our starting date to try to capture the period in which a price decline was more likely to be seen as a permanent shock. Here we report some sensitivity results around this starting date. Firstly, the results of the unit root tests are invariant to the starting date. As for cointegration, Table B.1 reports results for the years 1983-85. There is continuing support for cointegration.

Table B.1: Evidence of Cointegration when the starting date is changed[42]

	1983		1984		1985	
	Engle-Granger[43]	Johansen[44] LM	Engle-Granger	Johansen LM	Engle-Granger	Johansen LM
Total M&E						
Unrestricted	-3.01	40.04 **	-2.72	39.24 **	-2.50	35.72 **
Output equal to 1	-2.75	13.70	-3.40**	11.40	-3.40**	15.55

p-value in parentheses
** Significant at the 5% level.

Table B.2 reports long-run elasticity estimates over the years 1983-85. Estimates of the price elasticity show little significance and results also reflect continuing excess sensitivity to output.

Table B.2: Long-Run Estimates, Total Machinery and Equipment for 3 different years

	1983	1984	1985
constant	-22.12 ***	-23.84 ***	-23.39 ***
	(0.000)	(0.000)	(0.000)
y_t	2.43 ***	2.56 ***	2.53 ***
	(0.000)	(0.000)	(0.000)
c_t / p_t	0.04	0.14 *	0.12
	(0.522)	(0.098)	(0.184)
R-squared	0.97	0.96	0.96

p-value in parentheses
* Significant at the 10% level.
*** Significant at the 1% level.

[42] Critical values for the Engle-Granger test were taken from pp. 722 Davidson and MacKinnon (1993).
[43] Engle and Granger (1987).
[44] Johansen, (1988, 1991).

Table B.3 reports elasticities when the output elasticity coefficient is restricted to 1.0. A consistent pattern of user cost elasticities approximating 1.0 is obtained.[45]

Table B.3: Long Run Estimates – Output Restricted to 1, three different years

	1983	1984	1985
constant	-4.08 ***	-4.09 ***	-3.99 ***
	(0.000)	(0.000)	(0.000)
c_t / p_t	-0.95 ***	-0.97 ***	-0.91 ***
	(0.000)	(0.000)	(0.000)
y_t	1	1	1

p-value in parentheses
*** Significant at the 1% level.

[45] Sensitivity analysis to a wider range of starting dates led to an estimate of the user cost elasticity of 0.54 in 1978, Q1 and to 0.76 in 1987, Q3, both significant at the 5 per cent level. These results suggest that the period 1984-2002 contains the most persistent shock that enables us to identify the larger elasticity estimate.

Appendix C

Table C.1: Error Correction Model (1986:3 to 2002:3)

	Coefficients Freely Estimated	Output Restricted to 1
Adjustment Parameter		
ζ	0.15 **	-0.02
	(0.021)	(0.257)
Long Run Elasticities		
y_t	2.56 ***	1.0
	(0.000)	(0.000)
c_t / p_t	0.14 *	-0.97 ***
	(0.098)	(0.000)
Short Run Dynamics		
constant	0.00	0.03
	(0.896)	(0.306)
Δy_{t-1}	1.97 ***	2.22 ***
	(0.005)	(0.002)
Δy_{t-2}	0.12	0.17
	(0.859)	(0.81)
$\Delta(c_{t-1} / p_{t-1})$	-0.09	-0.09
	(0.506)	(0.516)
$ygap_{t-1}$	0.002	0.000
	(0.241)	(0.834)

p-values in parentheses
*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

Table C.2: Error Correction Model (1986:2 to 2002:2), Freely estimated by component

	Computers	Software	Telecomm. Equipment	Other M&E
Adjustment Parameter				
ζ	-0.09	-0.01	-0.18 *	-0.17 **
	(0.223)	(0.689)	(0.059)	(0.029)
Long Run Elasticities				
y_t	5.00 ***	2.65 ***	3.29 ***	1.15 ***
	(0.000)	(0.000)	(0.000)	(0.000)
c_t / p_t	-0.55 ***	-0.59 ***	0.11 *	0.07 ***
	(0.000)	(0.001)	(0.097)	(0.086)
Short Run Dynamics				
constant	0.05 ***	0.03 ***	0.008	-0.01
	(0.009)	(0.000)	(0.024)	(0.179)
Δy_{t-1}	0.56	0.325	2.47	2.91 ***
	(0.737)	(0.751)	(0.188)	(0.002)
Δy_{t-2}	0.69	0.01	-1.15	0.01
	(0.666)	(0.99)	(0.541)	(0.990)
$\Delta(c_{t-1} / p_{t-1})$	0.11	0.085	0.153	0.003
	0.601	(0.454)	(0.385)	(0.970)
$ygap_{t-1}$	-0.001	0.00	-0.002	0.005
	(0.715)	(0.966)	(0.689)	(0.141)

p-value in parentheses
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Table C.3: Error Correction Model (1986:2 to 2002:2), Restricted Estimates by component

	Computers	Software	Telecomm. Equipment	Other M&E
Adjustment Parameter				
ζ	-0.11 **	-0.02	-0.11 *	-0.20 ***
	(0.037)	(0.513)	(0.07)	(0.009)
Long Run Elasticities				
c_t / p_t	-1.05 ***	-1.02 ***	-0.54 ***	0.04
	(0.000)	(0.000)	(0.000)	(0.119)
y_t	1	1	1	1
Short Run Dynamics				
constant	0.06 ***	0.03 ***	0.01	-0.01
	(0.006)	(0.001)	(0.643)	(0.204)
Δy_{t-1}	0.52	0.26	2.11	2.85 ***
	(0.750)	(0.801)	(0.268)	(0.002)
Δy_{t-2}	0.81	0.02	-0.64	0.02
	(0.604)	(0.983)	(0.740)	(0.979)
$\Delta(c_{t-1} / p_{t-1})$	0.17	0.08	0.09	0.009
	(0.004)	(0.459)	(0.607)	(0.894)
$ygap_{t-1}$	0.004	0.00	-0.00	0.005 *
	(0.339)	(0.968)	(0.646)	(0.074)

p-value in parentheses
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.